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TUNE FEEDBACK AT RHIC

P. Cameron, P. Cerniglia, R. Connolly, J. Cupolo, W.C. Dawson, C. Degen, A. DellaPenna, J. DeLong, A. Drees, A. Huhn, M. Kesselman, A. Marusic, B. Oerter, J. Mead, C. Schultheiss, R. Sikora, J. van Zeijts
Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

Preliminary phase-locked loop betatron tune measurement results were obtained during RHIC 2000 with a resonant Beam Position Monitor. These results suggested the possibility of incorporating PLL tune measurement into a tune feedback system for RHIC 2001. Tune feedback is useful in a superconducting accelerator, where the machine cycle time is long and inefficient acceleration due to resonance crossing is not comfortably tolerated. This is particularly true with the higher beam intensities planned for RHIC 2001. We present descriptions of a PLL tune measurement system implemented in the DSP/FPGA environment of a RHIC BPM electronics module and the feedback system into which the measurement is incorporated to regulate tune. In addition, we present results from the commissioning of this system during RHIC 2001.

1 INTRODUCTION

While our experience with Schottky measurements in RHIC[1] has been extremely favorable, the usefulness of our 2.069GHz Schottky system[2] during acceleration of Gold beams is limited by the large width and resulting overlap of the revolution and betatron lines at and near injection energies, where the relativistic slip factor is large. Being familiar with the utility of 'quasi-Schottky' pickups at FNAL[3], we implemented a plan to resonate a pair (one for each ring in RHIC) of moveable dual-plane BPMs. These BPMs were resonated at 238MHz, and Schottky signals were successfully observed[4].

The primary difficulty in constructing a high sensitivity transverse pickup is the dynamic range problem which results from trying to see signals at the Schottky level in the presence of the coherent beam spectrum, which is typically at least 100dB stronger. In designing the PLL tune measurement system for RHIC 2001 we dealt with this problem in several ways. We placed the pickup resonance well above the coherent spectrum, at 8.5 times the 28MHz acceleration RF. We resonated only a difference mode so that the sum mode coherent signal remaining at the pickup frequency would not enjoy enhancement of its power by the Q of the difference mode. We utilized a moveable BPM so that the remaining difference mode coherent signal at the revolution harmonic could be minimized. We bandpass filter the output of the BPM before the first stage of amplification to avoid saturation. And finally, we employ a 1 KHz bandwidth narrowband filter at the baseband 78KHz input to the digitizer.

During the physics portion of the RHIC 2000 run the resonant pickup was used in a prototype PLL tune measurement system. With a kicker power of about 50μW continuously driving 4m long striplines, and using a commercial lock-in amplifier for phase detection, the tune was tracked with a precision of a few parts in 10^{-4} with no observable emittance blowup as monitored by the power in the 2GHz Schottky spectrum. Based upon our brief experience with that system we designed and built the tune feedback system described in the following sections.

2 PLL TUNE MEASUREMENT

In comparison with the turn-by-turn implementation of a PLL tune system[5,6], the resonant pickup approach has the advantages of requiring less kicker power, less real-time processing speed, and a less demanding interface to the timing system. Essential elements of this system are depicted in the Block Diagram on the next page.

2.1 System Description

At the core of the PLL tune system is a complement of versatile and easy-to-use custom numerically controlled oscillators[7], shown as NCOs A, B, and C in the block diagram. These NCOs sit in VME, and their clocks come from the 28MHz low level RF system, delivered from the RF Control Room to the Instrumentation Control Room via 600m of heliax cable. All frequencies in the tune system are thus synchronous with the beam. The output of NCO A is at the 78 KHz revolution frequency (i.e. RF/360). When the loop is locked and after x32 frequency multiplication, the output of NCO C is at 238MHz (i.e RFx8.5, or harmonic 3060) plus the betatron frequency. These frequencies are mixed in a suppressed carrier single sideband modulator. The output is at the betatron line above harmonic 3061, and is highpass filtered before entering a 10W class A amplifier. The output of the amplifier drives the 1m long 50 ohm kicker striplines through a difference hybrid and about 100m of heliax into the tunnel. The kicker excitation travels with the beam through the betatron-tune-dependent phase shift between the kicker and the resonant pickup. Pickup output at 238MHz is bandpass filtered, boosted by 30dB, and again transported via 100m of heliax to the mixer, whose output is again at 78KHz. The signal is delivered to the high impedance input of a Dynamic Signal Analyzer for FFT analysis and display, as well as to the 50 ohm input of the analog front end for amplification and filtering. By including the

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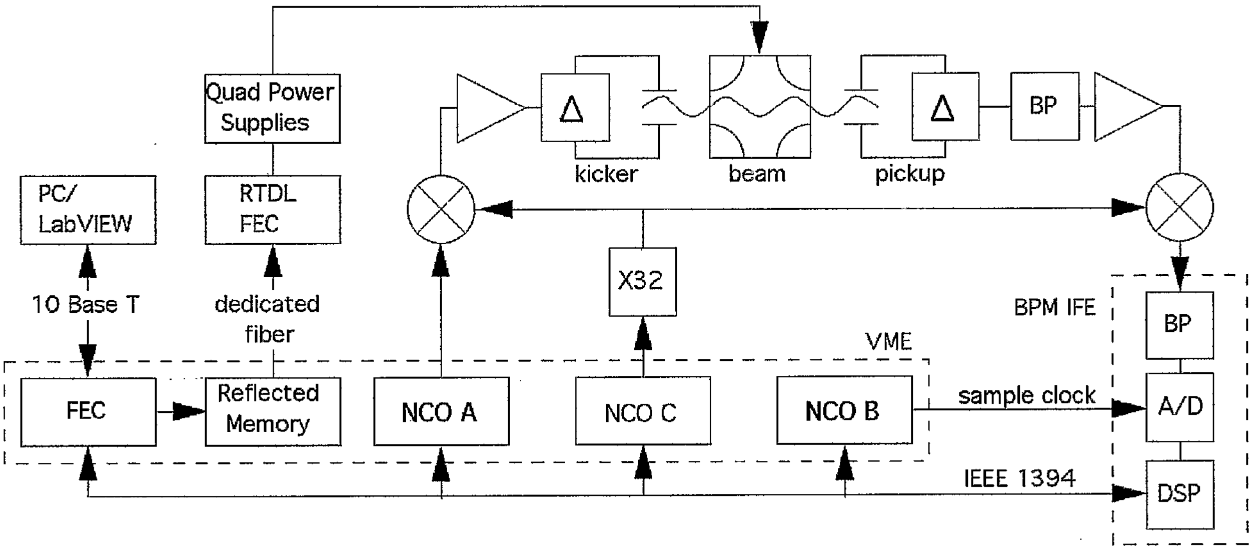
betatron frequency in the local oscillator for up and down conversion, the tune signal is always at the same frequency (78KHz), and the need for a tracking filter at the input to the digitizer is eliminated.

- Setup Parameters – LabVIEW writes record length, loop gain, estimated tune frequency and phase (from the BTF measurement), and PLL search window limits to the DSP.



The digitizer clock is generated by NCO B at 4x the frequency of NCO A (or 312KHz), permitting a simple I/Q demodulation[8] of the signal. The data is processed in the DSP of a modified RHIC BPM module[9]. The following functions are performed by the DSP:

- I/Q demodulation – samples have their signs corrected, and are alternately assigned to I and Q sum registers
- Phase compensation – the phase of the raw I and Q data is corrected for the initial phase at injection, plus the frequency dependent phase shift up the acceleration ramp. This phase shift totals a little over 360 degrees during the 0.3% frequency swing from injection to store, and the bulk of it originates in the cable lengths to and from the tunnel.
- Linewidth compensation – at 238 MHz the rms betatron linewidth is about 1 KHz at injection, extremely narrow at transition, and about 100 Hz at store. The loop gain is adjusted to compensate for linewidth up the ramp.
- NCO control – based on the above analysis the DSP updates the frequency of NCO C to track the betatron line.

The processing outlined above is performed on blocks of data, whose length typically varies between 32 bytes and 2KB. Update of the NCO is at around 100Hz. The DSP communicates with VME via IEEE1394.

High level control of the PLL system is accomplished with a MacIntosh running LabVIEW, communicating with VME via ethernet. The following functions are performed by the LabVIEW program:

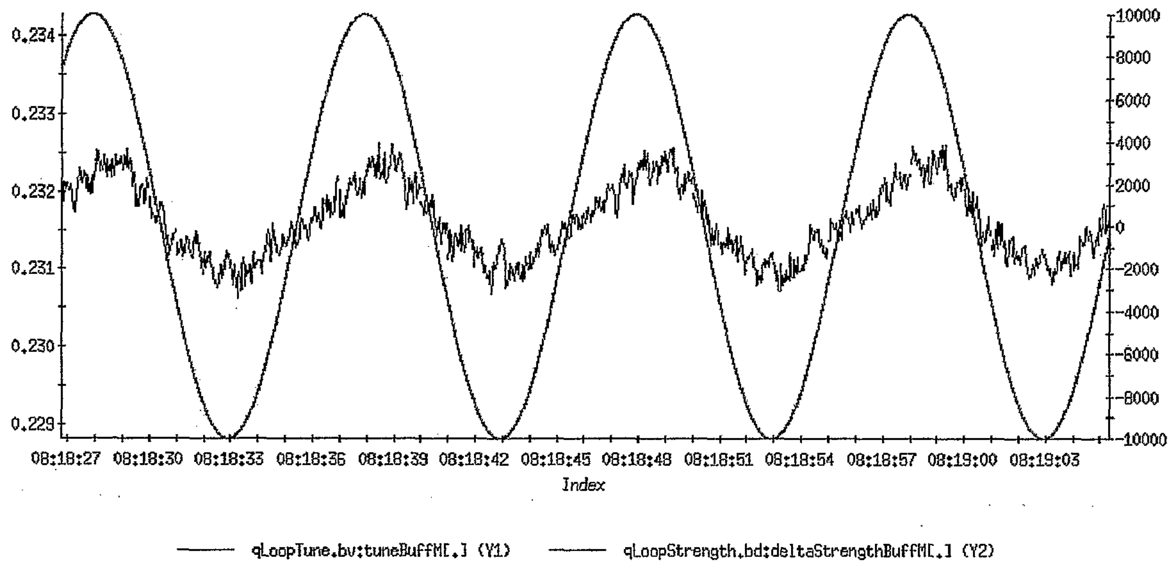
- Beam Transfer Function Measurement – LabVIEW assumes control of NCO C, sweeps the frequency across the betatron resonance, and records amplitude and phase.
- Ramp parameters – LabVIEW reads realtime magnetic rigidity from the 720Hz Real Time Data Link of the Control System and calculates RF frequency and relativistic slip factor. Using calculated RF frequency, the frequency-dependent phase shift thru the system is interpolated from a table of previously measured calibration phase and written to the DSP to permit phase correction of the raw I and Q data up the ramp. Using calculated slip factor, corrected loop gain is written to the DSP up the ramp.
- Automatic Gain Control – LabVIEW controls gain of the power amplifier via GPIB, based upon amplitude data from the DSP.
- Lock Indicator – LabVIEW writes a bit to VME indicating the presence or absence of loop lock, based on the magnitude of the corrected Q data.

2.2 Commissioning Results

At the time of this writing the PLL tune measurement system is in the midst of commissioning with beam. Loops have been locked and tune tracked simultaneously on horizontal and vertical planes at injection. Tune has been tracked up the ramp and through transition to store on a single plane. Both of these have been accomplished while the kicked tunemeter was operating, delivering instantaneous kicker power ~80dB above the PLL excitation every two seconds at random phase.

3 TUNE FEEDBACK

The tune feedback control loop is implemented as a digital control loop running in a power PC. The



horizontal and vertical tunes are converted to horizontal and vertical strengths through a matrix that relates the desired tune change to strengths. The horizontal and vertical strengths are not independent since this matrix contains cross terms. These strengths are then used to calculate the required magnet currents. As shown in the block diagram, magnet coefficients are calculated in the Front End Computer local to the PLL tune measurement, then transported via reflected memory and a dedicated fiber optic line to the power supply building 600m away, where quadrupole currents are written to the power supplies via the Real Time Data Link.

There are two loop compensation filters. The inputs for these filters are the tune errors for each plane. It is expected that the two planes will not have the same characteristics and the compensation filters will be used to adjust the two loops so they have equal response times. This is required due to the coupling between the strengths of the two planes.

The data in the above figure shows tune as measured by the PLL system during modulation of the quads at 0.1Hz. The magnitude of the measured tune modulation is in agreement with calculations. The phase shift of about 10 degrees is not yet fully understood. S/N ratio of the PLL tune system has been improved significantly since this measurement was accomplished.

4 CONCLUSIONS

All of the hardware for accomplishing tune feedback in RHIC is in place. Hardware and software refinements to improve the quality and reliability of the PLL tune measurement are in progress. When beam time becomes available complete magnet system transfer function measurements will be made. We expect at that time to be able to close the loop and regulate tune up the acceleration ramp.

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